the Final Rejection cited two patents, for the first time, to substantiate the Examiner's rejections. Since neither of those references had previously been cited by the Examiner, Applicants could not have earlier responded, by argumentation or by submitting counter-examples, to the specific language in the citations noted by the Examiner. The present Response, which is devoid of any claim amendments, therefore responds only to these new citations and the arguments based thereon made by the Examiner in the Final Rejection, and therefore these exhibits could not have been earlier submitted. Although the issue for which the exhibits are presented has been discussed throughout prosecution, the need for exhibits having specific language to counter the language relied upon by the Examiner in the references cited for the first time in the Office Action has necessitated this Response. In order to permit Applicants to rely on these exhibits in their Appeal Brief, they have been re-submitted herewith. The present response, therefore, satisfies all of the preconditions for entry under 37 C.F.R.§ 1.116. Except for the absence of amendments, the following discussion is identical to the discussion in Amendment "C". Applicants therefore submit the present Response does not raise any new issues requiring further searching or consideration, and entry of the present Response is therefore respectfully requested.

Claims 1-14 were rejected under 35 U.S.C. §102(e) as being anticipated by Parker et al. Claim 15 was rejected under 35 U.S.C. §103(a) as being unpatentable over Parker et al. in view of Choi. Claims 16-19 and 22 were rejected under 35 U.S.C. §103(a) as being unpatentable over Parker et al. in view of "official notice" of the use of the different technologies respectively set forth in these dependent claims. Claim 20 was rejected under 35 U.S.C. §103(a) as being unpatentable over Parker

et al. in view of Shiigi. Claim 21 was rejected under 35 U.S.C. §103(a) as being unpatentable over Parker et al. in view of Layton et al.

These rejections are respectfully traversed for the following reasons. As argued in Applicants' previous response, wherein the Parker et al. reference was relied upon as the primary reference for rejecting the claims, there is no disclosure in the Parker et al. reference describing the generation or transmission of images. The Parker et al. reference is exclusively concerned with the generation and transmission of text data, possibly combined with a representation of an electrical signal, such as an ECG. Applicants argued that an ECG is simply a trace or a curve, representing a single electrical signal, and does not represent a medical examination image, as that term is commonly understood by those of ordinary skill in the field of medical imaging. Applicants continue to believe this is a relevant basis for traversing the above rejections based on Parker et al.

In response to those previously-submitted arguments, at page 10 of the Office Action (paragraph 40) the Examiner provided citations to two patents that the Examiner considers as supporting a definition of "medical examination image" or "imaging modality" that encompasses the representation of an ECG. Applicants respectfully submit that the Examiner's reliance on these citations is incorrect.

The Examiner cited the Manning et al. reference as defining "imaging modality" as "any imaging modality that acquires imaging data by a process that can be disturbed by body motions." Applicants have no disagreement with this definition, however, it is merely a tautology, since it defines "imaging modality" in terms of the acquisition of "imaging data," and Applicants do not agree that an ECG is considered by those of ordinary skill in the field of medical imaging as "imaging data." As noted

above, an ECG is simply a curve or a trace, and is not an image. This definition, therefore, merely shifts the question of what is an "imaging modality" to the question of what are "imaging data," and therefore provides no support for the position that an ECG system is an "imaging modality" nor that "imaging data" encompass an ECG (by itself).

The Examiner also cited the Hutson reference as listing "multiple modalities of medical imaging," among which electrocardiography (EKG) is listed. The Examiner, however, has only partially quoted the sentence in which that phrase occurs in the Hutson reference. The complete sentence begins "The system and method of the present invention correlate *data* from multiple modalities for medical imaging, including... ." This sentence, therefore, is describing data (without restriction) that can be obtained from any number of imaging modalities, and the listing therefore not only includes the imaging modalities themselves, but also the data that can be acquired therefrom. Applicants acknowledge that an ECG can be *obtained from* an imaging modality, since ECG monitoring and ECG triggering are commonly used in the production of medical images. Simply because an ECG is available from an imaging modality, as being among the total available data from that imaging modality, does not mean that the ECG itself is considered by those of ordinary skill in the field of medical imaging as a "medical examination image," as set forth in the claims of the present application. Moreover, it is clear from the drawings of the Hutson reference that the method and system described therein would have no, or extremely little, utility in processing an ECG signal. The drawings clearly indicate that true medical examination images are being processed in the Hutson reference. It is not seen how the techniques shown in Figures 6 through 13 of the Hutson

reference, for example, could have any applicability whatsoever to processing an ECG signal. Therefore, it is clear that the complete statement in the Hutson reference, of which the Examiner cited only a portion, includes electrocardiography in the listing not as an example of a medical image, but as an example of data that can be acquired, *in addition to medical images*, from an imaging modality.

Numerous standard texts and dictionaries support the position of the Applicants that the term "medical examination image" is not considered by those of ordinary skill in the field of medical imaging to encompass an ECG.

Attached hereto as Attachment "A" is a printout from the online encyclopedia *Wikopedia*, describing medical imaging in general. As can be seen from that excerpt, a number of categories of medical imaging are listed, none of which mentions ECG, even as an augmentation. Moreover, the online article provides a number of links to other articles in the encyclopedia, and none of these links is to any other section of the online encyclopedia that is directed to electrocardiography. Therefore, not only is there no reference to electrocardiography, as an example of medical imaging, in the article itself, but the authors obviously did not even consider electrocardiography as being sufficiently related to medical imaging to include it in any of the links.

Attached hereto as Attachment "B" is an excerpt from the *McGraw-Hill Dictionary of Scientific and Technical Terms*, providing a definition of medical imaging as the production of visual representations of body parts, tissues or organs. This definition clearly does not encompass an ECG, and electrocardiography is not listed as being among the general categories of medical imaging provided in that definition.

Attachment "C" is an excerpt from a standard medical text (*Foundations of Medical Imaging*), and in the introduction, that provides an overview of all types of medical imaging that will treated in the text, a definition is provided in the third full paragraph at page 4, stating that modern or contemporary medical imaging is a two-part process: (1) the collection of data concerning the interaction of some form of radiation with tissue, and (2) the transformation of these data into an image (or a set of images) using specific mathematical methods and computational tools. Clearly an ECG is simply a measurement of an electrical signal, and does not involve the interaction of radiation with a subject. In this regard, it is no different than a curve representing a measurement of blood pressure, temperature, etc., and thus falls into the category of "sensing" rather than "imaging." An excerpt from another standard text (*Principles of Medical Imaging"*) Is attached hereto as "Attachment "D". In the Preface to that textbook, the various categories of medical imaging (imaging modalities) are listed, and clearly ECG is not included.

Applicants respectfully submit that the attachments hereto are highly representative of the meaning that those of ordinary skill in the field of medical imaging ascribe to the term "medical examination images," and they clearly demonstrate that those of ordinary skill do not ordinarily consider an ECG to fall within that definition.

In the context of the patentability of the claims of the present application, this is not simply a trivial or semantic distinction. The fact that the Parker et al. reference does not provide any disclosure whatsoever with regard to acquiring or transmitting medical examination images, as that term is commonly understood by those of ordinary skill in the field of medical imaging, is sufficient to overcome the anticipation

rejection of claims 1-14 based on the Parker et al. reference, since the Parker et al. reference does not disclose all of the elements of claim 1 as arranged and operating in that claim. Claims 2-14 add further structure to the novel combination of claim 1, and therefore are not anticipated by Parker et al. for the same reasons.

As to the rejections under 35 U.S.C. §103(a) wherein Parker et al. is relied upon as the primary reference, in combination with respective secondary references or "official notice," the distinction between a "medical examination image" and an ECG is relevant because, in order to substantiate a rejection under 35 U.S.C. §103(a) based on a modification of the Parker et al. reference, the Examiner must provide evidentiary support for the position that it would have been obvious to a person of ordinary skill in the field of medical imaging to make use of the teachings of Parker et al., which are exclusively directed to the generation and transmission of an ECG, for the purpose of generating and transmitting true "medical examination images." In view of the above evidence showing that those of ordinary skill in the field of medical imaging do not consider an ECG to fall into the category of a "medical examination image," Applicant respectfully submits the Examiner cannot simply conclude, without proper evidentiary support, that there is no difference between the two. Applicants respectfully submit the Examiner has not provided the proper evidentiary support required by numerous decisions of the United States Court of Appeals for the Federal Circuit indicating a motivation, inducement or guidance in any of the references of record to apply the teachings of Parker et al., which are exclusively disclosed in that reference in the context of ECG generation and transmission, to the generation and transmission of "medical examination images." In view of the significant differences between an ECG and a true "medical

examination image," Applicants respectfully submit that even if a person of ordinary skill in the field of medical imaging had the insight to apply the ECG-based teachings of Parker et al. to the field of medical imaging, this would be an insight supporting patentability, rather than a basis for negating patentability.

Applicants therefore respectfully submit that none of claims 16-22 would have been obvious to a person of ordinary skill in the field of medical imaging based on the teachings of Parker et al., modified by any of the secondary references or "official notice" cited by the Examiner.

The present Amendment does not raise new issues requiring further searching or consideration. The attachments submitted herewith have been submitted because of the citation, for the first time, of the Manning and Hutson references by the examiner in the final rejection. Until the Examiner provided the (alleged) definitions in those references, Applicants had no reason to submit any type of evidence to refute those (erroneous) definitions. Moreover, all of the attachments hereto are submitted in the context of the issue that was raised by the Applicants in Applicants' initial response, and therefore this issue is not a new issue. Entry of the present Amendment is therefore respectfully requested.

Submitted by,

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Medical imaging

From Wikipedia, the free encyclopedia.
(Redirected from Medical Imaging)

It has been suggested that this article or section be merged into *Radiology*. (Discuss)

Medical imaging is the process by which physicians evaluate an area of the subject's body that is not externally visible. Medical imaging may be clinically motivated, seeking to diagnose and examine disease in specific human patients (*see* pathology). Alternatively, it may be used by researchers in order to understand processes in living organisms. Many of the techniques developed for medical imaging also have scientific and industrial applications.

Medical imaging often involves the solution of mathematical inverse problems. This means that cause (the properties of living tissue) is inferred from effect (the observed signal). In the case of ultrasonography the probe consists of ultrasonic pressure waves and echoes inside the tissue show the internal structure. In the case of radiography, the probe is X-ray radiation which is absorbed at different rates in different tissue types such as bone, muscle and fat.

Contents

Origins

In its most primitive form, imaging can refer to the physician simply feeling an area of the body in order to visualize the condition of internal organs. This was used historically to diagnose aortic aneurysms, fractures, enlarged internal organs, and many other conditions. It remains an important step today in making initial assessments of potential problems, although additional steps are often used to confirm a diagnosis. The primary drawbacks of this approach are that the interpretation may be quite subjective and that recording the 'image' is difficult.

Modern imaging technology

ATTACHMENT "A"

Radiographs

Main article: Radiography

Radiographs, more commonly known as x-rays, are often used to determine the type and extent of a fracture as well as for detecting pathological changes in the lungs. With the use of radio-opaque contrast media, such as barium, they can also be used to visualize the structure of the stomach and intestines - this can help diagnose ulcers or certain types of colon cancer.

Fluoroscopy

Main article: Fluoroscopy

Fluoroscopy produces real-time images of internal structures of the body in a similar fashion to Radiography, but employs a constant input of x rays. It is often used in image-guided procedures when constant feedback during a procedure is required.

Computed tomography

Main article: Computed tomography

A CT scan, also known as a CAT scan (Computed Axial Tomography scan), traditionally produces a 2D image of the structures in a thin section of the body. It uses ionizing radiation such as X-rays and thus repeated scans should be avoided.

Magnetic resonance imaging

Main article: Magnetic resonance imaging

An MRI uses powerful magnets to excite hydrogen nuclei in water molecules in human tissue, producing a detectable signal. Like a CT scan, an MRI traditionally creates a 2D image of a thin "slice" of the body. As an MRI does not use ionizing radiation, it is the preferred imaging method for children and pregnant women.

Ultrasound

Main article: Medical ultrasonography

Medical ultrasonography uses high frequency sound waves of between 2.0 to 10.0 megahertz that are reflected by tissue to varying degrees to produce a 2D image, traditionally on a TV monitor. This is often used to visualize the fetus in pregnant women. Other important uses include imaging the abdominal organs, heart, male genitalia and the veins of the leg. While it may provide less anatomical information than techniques such as CT or MRI, it has several advantages which make it ideal as a first line test in numerous situations, in particular that it studies the function of moving structures in real-time. It is also very safe to use, as the patient is not exposed to radiation and the ultrasound does not appear to cause any adverse effects. It is also relatively cheap and quick to perform. Ultrasound scanners can be taken to critically ill patients in intensive care units saving the danger of moving the patient to the radiology department. The real time moving image obtained can be used to guide drainage and biopsy procedures. Doppler capabilities on modern scanners allow the blood flow in arteries and veins to be assessed.

Creation of three-dimensional images

Recently, techniques have been developed to enable CT, MRI and Ultrasound scanning software to produce 3D images or the physician. Traditionally CT and MRI scans produced 2D static output on film. To produce 3D images, many scans are made, then combined by computers to produce a 3D model, which can then be manipulated by the physician. 3D ultrasounds are produced using a somewhat similar technique.

With the ability to visualize important structures in great detail, 3D visualization methods are a valuable resource for the diagnosis and surgical treatment of many pathologies. It was a key resource (and also the cause of failure) for the famous, but ultimately unsuccessful attempt by Singaporean surgeons to separate Iranian twins Ladan and Laleh Bijani in 2003. The 3D equipment was used previously for similar operations with great success.

Other imaging techniques

Other proposed or developed medical imaging techniques (often termed *modalities*) include:

- diffuse optical tomography
- elastography
- electrical impedance tomography
- nuclear medicine
- optoacoustic imaging
- ophthalmology
  - A-scan
  - B-scan
  - corneal topography
  - Heidelberg retinal tomography
  - Optical coherence tomography
  - scanning laser ophthalmoscopy
- positron emission tomography

Some of these techniques are still at a research stage and not yet used in clinical routines.

Non-diagnostic imaging

Neuroimaging has also been used in experimental circumstances to allow people (especially disabled persons) to control outside devices, acting as a direct mind-computer interface.

External links

- Imaging-Centers.com (http://www.imaging-centers.com/) is the first searchable directory of medical imaging centers across the United States.

See also

- Medical test
- Medical examination
- PACS
- Tomogram
- Digital Imaging and Communications in Medicine (image format)
- Biomedical informatics

Retrieved from "http://en.wikipedia.org/wiki/Medical_imaging"

Categories: Articles to be merged | Medical imaging | Radiology | Image processing | Nuclear medicine

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McGraw-Hill Dictionary of Scientific and Technical Terms

Fifth Edition

Sybil P. Parker
Editor in Chief

McGraw-Hill, Inc.
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Montreal New Delhi San Juan Singapore Sydney Tokyo Toronto

ATTACHMENT "B"

On the cover: Photomicrograph of crystals of vitamin B_1.
(Dennis Kunkel, University of Hawaii)

In addition, material has been drawn from the following references: R. E. Huschke, *Glossary of Meteorology*, American Meteorological Society, 1959; *U.S. Air Force Glossary of Standardized Terms*, AF Manual 11-1, vol. 1, 1972; *Communications-Electronics Terminology*, AF Manual 11-1, vol. 3, 1970; W. H. Allen, ed., *Dictionary of Technical Terms for Aerospace Use*, 1st ed., National Aeronautics and Space Administration, 1965; J. M. Gilliland, *Solar-Terrestrial Physics: A Glossary of Terms and Abbreviations*, Royal Aircraft Establishment Technical Report 67158, 1967; *Glossary of Air Traffic Control Terms*, Federal Aviation Agency; *A Glossary of Range Terminology, White Sands Missile Range, New Mexico*, National Bureau of Standards, AD 467-424; *A DOD Glossary of Mapping, Charting and Geodetic Terms*, 1st ed., Department of Defense, 1967; P. W. Thrush, comp. and ed., *A Dictionary of Mining, Mineral, and Related Terms*, Bureau of Mines, 1968; *Nuclear Terms: A Glossary*, 2d ed., Atomic Energy Commission; F. Casey, ed., *Compilation of Terms in Information Sciences Technology*, Federal Council for Science and Technology, 1970; *Glossary of Stinfo Terminology*, Office of Aerospace Research, U.S. Air Force, 1963; *Naval Dictionary of Electronic, Technical, and Imperative Terms*, Bureau of Naval Personnel, 1962; *ADP Glossary*, Department of the Navy, NAVSO P-3097.

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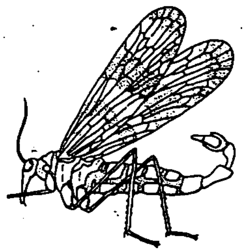
in the fetal intestine, becoming the first fecal discharge of the newborn. { mə'kō·nē·əm }

meconium ileus [MED] Intestinal obstruction in the newborn with cystic fibrosis due to trypsin deficiency. { mə'kō·nē·əm 'il·ē·əs }

MECOPTERA



2 mm

orpion fly *(Panorpa)*.

Mecoptera [INV ZOO] The scorpion flies, a small order of insects; adults are distinguished by the peculiar prolongation of the head into a beak, which bears chewing mouthparts. { me'käp·tə·rə }

mecystasis [PHYSIO] Increase in muscle length with maintenance of the original degree of tension. { me'sis·tə·səs }

media [HISTOL] The middle, muscular layer in the wall of a vein, artery, or lymph vessel. { 'mē·dē·ə }

media conversion [COMPUT SCI] The transfer of data from one storage type (such as punched cards) to another storage type (such as magnetic tape). { 'mē·dē·ə kən,vər·zhən }

media conversion buffer [COMPUT SCI] Large storage area, such as a drum, on which data may be stored at low speed during nonexecution time, to be later transferred at high speed into core memory during execution time. { 'mē·dē·ə kən,vər·zhən ,bəf·ər }

mediad [ANAT] Toward the median line or plane of the body or of a part of the body. { 'mē·dē,ad }

medial [ANAT] **1.** Being internal as opposed to external (lateral). **2.** Toward the midline of the body. [SCI TECH] Located in the middle. { 'mē·dē·əl }

medial arteriosclerosis [MED] Calcification of the tunica media of small and medium-sized muscular arteries. Also known as medial calcinosis; Mönckeberg's arteriosclerosis. { 'mē·dē·əl ,är·tir·ē·ō·sklə'rō·səs }

medial calcinosis *See* medial arteriosclerosis. { 'mē·dē·əl ,kal·sə'nō·səs }

medial lemniscus [ANAT] A lemniscus arising in the nucleus gracilis and nucleus cuneatus of the brain, crossing immediately as internal arcuate fibers, and terminating in the posterolateral ventral nucleus of the thalamus. { 'mē·dē·əl lem'nis·kəs }

medial moraine [GEOL] **1.** An elongate moraine carried in or upon the middle of a glacier and parallel to its sides. **2.** A moraine formed by glacial abrasion of a rocky protuberance near the middle of a glacier. { 'mē·dē·əl mə'rān }

medial necrosis [MED] Death of cells in the tunica media of arteries. Also known as medionecrosis. { 'mē·dē·əl ne'krō·səs }

media migration [CHEM ENG] Carryover of fibers or other filter material by liquid effluent from a filter unit. { 'mē·dē·ə mī'grā·shən }

median [MATH] **1.** Any line in a triangle which joins a vertex to the midpoint of the opposite side. **2.** The line that joins the midpoints of the nonparallel sides of a trapezoid. Also known as midline. [SCI TECH] Located in the middle. [STAT] An average of a series of quantities or values; specifically, the quantity or value of that item which is so positioned in the series, when arranged in order of numerical quantity or value, that there are an equal number of items of greater magnitude and lesser magnitude. { 'mē·dē·ən }

median effective dose *See* effective dose 50. { 'mē·dē·ən i'fek·tiv 'dōs }

median infective dose *See* infective dose 50. { 'mē·dē·ən in'fek·tiv 'dōs }

median lethal dose *See* lethal dose 50. { 'mē·dē·ən 'lēth·əl 'dōs }

median lethal time [MICROBIO] The period of time required for 50% of a large group of organisms to die following a specific dose of an injurious agent, such as a drug or radiation. { 'mē·dē·ən 'lēth·əl ,tīm }

median mass [GEOL] A less disturbed structural block in the middle of an orogenic belt, bordered on both sides by orogenic structure, thrust away from it. Also known as betwixt mountains; Zwischengebirge. { 'mē·dē·ən 'mas }

median maxillary cyst [MED] Cystic dilation of embryonal inclusions in the incisive fossa or between the roots of the central incisors. Also known as nasopalatine cyst. { 'mē·dē·ən 'mak·sə,ler·ē ,sist }

median nasal process [EMBRYO] The region below the frontonasal sulcus between the olfactory sacs; forms the bridge and mobile septum of the nose and various parts of the upper jaw and lip. { 'mē·dē·ən 'nāz·əl ,prä·səs }

median nerve test [MED] A test for loss of function of the median nerve by having the patient abduct the thumb at right angles to the palm with fingertips in contact and forming a pyramid. { 'mē·dē·ən 'nərv ,test }

median particle diameter [GEOL] The middlemost particle diameter of a rock or sediment, larger than 50% of the diameter in the distribution and smaller than the other 50%. { 'mē·dē·ən 'pärd·ə·kəl dī,am·əd·ər }

median point [MATH] The point at which all three medians of a triangle intersect. { 'med·ē·ən ,pȯint }

median strip [CIV ENG] A paved or planted section dividing a highway into lanes according to direction of travel. { 'mē·dē·ən 'strip }

mediastinitis [MED] Inflammation of the mediastinum. { ,mē·dē,as·tə'nīd·əs }

mediastinum [ANAT] **1.** A partition separating adjacent parts. **2.** The space in the middle of the chest between the two pleurae. { ,mē·dē·ə'stī·nəm }

medical bacteriology [MED] A branch of medical microbiology that deals with the study of bacteria which affect human health, especially those which produce disease. { 'med·ə·kəl bak,tir·ē'äl·ə·jē }

medical chemical engineering [CHEM ENG] The application of chemical engineering to medicine, frequently involving mass transport and separation processes, especially at the molecular level. { 'med·ə·kəl 'kem·ə·kəl ,en·jə'nir·iŋ }

medical climatology [MED] The study of the relation between climate and disease. { 'med·ə·kəl ,klī·mə'täl·ə·jē }

medical electronics [ELECTR] A branch of electronics in which electronic instruments and equipment are used for such medical applications as diagnosis, therapy, research, anesthesia control, cardiac control, and surgery. { 'med·ə·kəl i,lek'trän·iks }

medical entomology [MED] The study of insects that are vectors for diseases and parasitic infestations in humans and domestic animals. { 'med·ə·kəl ,en·tə'mäl·ə·jē }

medical ethics [MED] Principles and moral values of proper medical conduct. { 'med·ə·kəl 'eth·iks }

medical examiner [MED] A professionally qualified physician duly authorized and charged by a governmental unit to determine facts concerning causes of death, particularly deaths not occurring under natural circumstances, and to testify thereto in courts of law. { 'med·ə·kəl ig'zam·ə·nər }

medical frequency bands [COMMUN] A collection of radio frequency bands allocated to medical equipment in the United States. { 'med·ə·kəl 'frē·kwən·sē ,banz }

medical genetics [GEN] A field of human genetics concerned with the relationship between heredity and disease. { 'med·ə·kəl jə'ned·iks }

medical geography [MED] The study of the relation between geographic factors and disease. { 'med·ə·kəl jē'äg·rə·fē }

medical history [MED] An account of a patient's past and present state of health obtained from the patient or relatives. { 'med·ə·kəl 'his·trē }

medical imaging [MED] The production of visual representations of body parts, tissues, or organs, for use in clinical diagnosis; encompasses x-ray methods, magnetic resonance imaging, single-photon-emission and positron-emission tomography, and ultrasound. { 'med·ə·kəl 'im·ij·iŋ }

medical microbiology [MED] The study of microorganisms which affect human health. { 'med·ə·kəl ¦mī·krō·bī'äl·ə·jē }

medical mycology [MED] A branch of medical microbiology that deals with fungi that are pathogenic to humans. { 'med·ə·kəl mī'käl·ə·jē }

medical parasitology [MED] A branch of medical microbiology which deals with the relationship between humans and those animals which live in or on them. { 'med·ə·kəl ,par·ə·si'täl·ə·jē }

medical protozoology [MED] A branch of medical microbiology that deals with the study of Protozoa which are parasites of humans. { 'med·ə·kəl ,prō·dō·zō'äl·ə·jē }

medical radiography [MED] The use of x-rays to produce photographic images for visualizing internal anatomy as an aid in diagnosis. { 'med·ə·kəl ,rād·ē·'äg·rə·fē }

medication [MED] **1.** A medicinal substance. **2.** Treatment by or administration of a medicine. { ,med·ə'kā·shən }

medicinal [MED] Of, pertaining to, or having the nature of medicine. { mə'dis·ən·əl }

medicinal oil [MATER] A highly refined, colorless, tasteless and odorless petroleum oil used medicinally as an internal lu-

FOUNDATIONS OF MEDICAL IMAGING

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1

INTRODUCTION

The study of medical imaging is concerned with the interaction of all forms of radiation with tissue and the development of appropriate technology to extract clinically useful information from observations of this interaction. Such information is usually displayed in an image format. Medical images can be as simple as a projection or shadow image—as first produced by Röntgen nearly 100 years ago and utilized today as a simple chest X-ray—or as complicated as a computer reconstructed image—as produced by computerized tomography (CT) using X-rays or by magnetic resonance imaging (MRI) using intense magnetic fields.

Although, strictly speaking, medical imaging began in 1895 with Röntgen's discoveries of X-rays and of the ability of X-rays to visualize bones and other structures within the living body [1], contemporary medical imaging began in the 1970s with the advent of computerized tomography [2, 3]. Early, or what we call *classical*, medical imaging utilizes images that are a direct manifestation of the interaction of some form of radiation with tissue. Three examples will illustrate what we mean by classical imaging. First is the conventional X-ray procedure in which a beam of X-rays is directed through the patient onto a film. The developed film provides a shadow image of the patient which is a direct representation of the passage of X-rays through the body. Although such images are not quantitative, they do provide some measure of the attenuation of X-rays in tissue. Thus a section of soft tissue will appear darker than an equally thick section of bone, which attenuates more of the X-rays. It should be noted that even with current technological developments

conventional X-ray imaging still represents the major imaging procedure at most medical facilities.

As a second example of classical imaging, consider a conventional nuclear medicine procedure. Here a radioactive material is injected into the patient and its course followed by a detector which is moved over the patient in a specified manner. Although the image recorded by the detector generally has poor spatial resolution, its real advantage is that it provides a measure of physiological function from the time course of the radioisotope uptake. Clearly the conventional nuclear medicine image is a direct measure of the location and concentration of the radioactive isotope used.

As a final example of classical imaging, consider conventional medical ultrasound. Here, a pulse of ultrasonic energy is propagated into the patient and the backscattered echo signal is recorded by the same transducer. By angulating or moving the transducer (or by using a transducer array) positionally sequential echo signals are recorded, and a cross-sectional image of the subject is displayed directly on a video monitor. Ultrasound images are really a mapping of echo intensities and are a direct result of the interaction of the ultrasound pulse with tissue.

In this text we will define modern or contemporary medical imaging operationally as a two-part process: (1) the collection of data concerning the interaction of some form of radiation with tissue, and (2) the transformation of these data into an image (or a set of images) using specific mathematical methods and computational tools. Note that our definitions for both classical and modern imaging are consistent with our general definition of medical imaging, given in the first paragraph of this chapter. Note also that modern imaging can be represented as a generalization of classical imaging and that classical imaging is simply a special case of modern imaging in which the image forms directly from the interaction process. Whereas classical imaging is direct and intuitive, modern imaging is indirect and, in many cases, counter intuitive. Since modern images are formed by processing, reformulating, or reconstructing an image from the tissue/radiation interaction data base, the process is often referred to as "reconstruction" and the image as a "reconstructed image."

The first device capable of producing true reconstructed images was developed by G. N. Hounsfield [2] in 1972 at EMI in England. Hounsfield's X-ray computerized tomograph device was based in part on mathematical methods developed by A. M. Cormack [4] a decade earlier. For their efforts Hounsfield and Cormack were awarded the Nobel Prize in medicine in 1979. Put quite simply, CT imaging is based on the mathematical formalism that states that if an object is viewed from a number of different angles, then a cross-sectional image of it can be computed (or "reconstructed"). Thus X-ray CT yields an image that is essentially a mapping of X-ray attenuation or tissue density.

The introduction of X-ray CT in 1972 represents the real beginning of modern imaging and has altered forever our concept of imaging as merely

Table 1-1 3-D image reconstruction algorithms

2-D and 3-D Projection Reconstruction	2-D Projection Reconstruction	Parallel-Beam Mode
		Fan-Beam Mode
	3-D Projection Reconstruction	Parallel-Beam Mode
		Cone-Beam Mode
Iterative Method	Algebraic Reconstruction Technique (ART)	
	Maximum Likelihood Reconstruction (MLR) or Expectation Maximization (EM) Reconstruction	
Fourier Reconstruction	Direct Fourier Reconstruction (DFR)	
	Direct Fourier Imaging (DFI) in NMR	

taking a picture. It has also led to the development of 3-D imaging and is making quantitative imaging a reality. The application of reconstructive tomography to conventional nuclear medicine imaging has led to the development of two new imaging modalities: single photon emission computed tomography (SPECT) and positron emission tomography (PET). Similar applications to the laboratory technique of nuclear magnetic resonance (NMR) has led to magnetic resonance imaging (MRI). The CT concept is currently being extended to 3-D magnetoencephalography, electrical impedance tomography, and photon migration tomography, to name a few. Inherent to the development of these new imaging modalities has been the development of new reconstruction techniques, which are detailed in Table 1-1.

In this chapter we seek to provide a brief historical perspective for the various medical imaging modalities that are currently important. The various techniques are shown in Figs. 1-1 and 1-2 where they are characterized by the interrogation wavelengths. A parallel sequence will be followed in the succeeding chapters which provide more detailed discussions of the various imaging modalities. Although the various imaging techniques will, of necessity, be treated separately, our goal is to provide a unified approach to the field of medical imaging.

1-1 THE BEGINNING WITH X-RAYS

The history of medical imaging really began on November 8, 1895, when Wilhelm Konrad Röntgen reported the discovery of what he called "a new

Principles of Medical Imaging

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ATTACHMENT "D"

Cover photograph courtesy of Michael B. Smith. A computer model of the human head showing the naturally occuring magnetic field gradients found in all normal humans when exposed to a homogeneous, static magnetic field of 1 tesla. Each contour line describes a field change of 0.3 parts per million. The differences in the magnetic field are due to the magnetic susceptibility of the air–tissue interface associated with the sinus cavities in the head.

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Preface

The field of medical imaging is growing at a rapid pace. Since the early 1960s, three new imaging modalities, namely, radionuclide imaging, ultrasound, and magnetic resonance imaging, have appeared and matured. Along with X-ray they are among the most important clinical diagnostic tools in medicine today. Radionuclide imaging, although its resolution cannot match that of other modalities, uses radioactive isotopes attached to biochemically active substances to yield unique information about the biochemical or physiological function of the organ which is unattainable otherwise. Ultrasound scanners use high frequency sound waves to interrogate the interior of the body. They are capable of depicting anatomical details with excellent resolution. Ultrasound is particulary suited to situations where exposure to ionizing radiation is undesirable, such as in obstetrical and neonatal scanning, and to imaging structures in motion, such as heart valves. Magnetic resonance imaging, however, has been envisioned to be the most exciting of them all by far because it also uses a form of nonionizing radiation, can achieve superior resolution, and is capable of yielding physiological information. In this period, significant progress has also been achieved in conventional X-ray radiography. Improved design or introduction of better materials in image intensifiers, intensifying and fluoroscopic screens, and photographic films has enhanced the resolution to a significant degree without adding higher patient radiation exposure levels. It is therefore plausible to understand why conventional radiography is still routinely used clinically for the diagnosis of many diseases and is the gold standard to which newer imaging modalities are compared.

Unquestionably, the digital revolution is the primary reason that has caused the medical imaging field to experience the explosive growth that we are seeing today. Computer and digital technology along with advances in electronics have made data acquisition fast and mass data storage possible. These are the most essential ingredients for the practical realization of tomographical reconstruction principles. X-ray computed tomography (CT), digital radiography, real-time ultrasonic scanners, single-photon emission computed tomography (SPECT), positron emission tomography (PET), and magnetic resonance imaging (MRI), which came about after the early 1970s, are just a few well-known products of the digital revolution in medical imaging.

While the development of these new imaging approaches may have contributed greatly to the improvement of health care, it has also contributed to the rising cost of health care. A chest X-ray costs only \$20–30 per procedure whereas a magnetic resonance scan may cost up to \$1000, let alone the expenses associated with acquiring and installing such a scanner. The cost-to-benefit ratio for

these expensive procedures in certain cases is sometimes not as clear as in others. Therefore it is not unusual that the clinical efficacy and contribution of these modalities to patient care are being scrutinized and debated constantly by the medical community as well as the public.

This book is intended to be a university textbook for a senior or first-year graduate level course in medical imaging offered in a biomedical engineering, electrical engineering, medical physics, or radiological sciences department. Much of the material is calculus based. However, an attempt has been made to minimize mathematical derivation and to place more emphasis on physical concepts. A major part of this book was derived from notes used by the authors to teach a graduate course in medical imaging at the Bioengineering Program of Pennsylvania State University since the late 1970s. This book covers all four major medical imaging modalities, namely, X-ray including CT and digital radiography, ultrasound, radionuclide imaging including SPECT and PET, and magnetic resonance imaging. It is divided into four chapters in which a similar format is used. In each chapter fundamental physics involved in a modality is given first, followed by a discussion on instrumentation. Then various diagnostic procedures are described. Finally, recent developments and biological effects of each modality are discussed. At the end of each chapter a list of relevant references, further reading materials, and a set of problems are given. The purpose of this textbook is to give students with an adequate background in mathematics and physics an introduction to the field of diagnostic imaging; the materials discussed should be more than sufficient for one semester. However, the book may also be used as the text for a two-semester course in medical imaging when supplemented by additional materials or by inclusion of more mathematic detail.

Although this book has been written as a college textbook, radiologists with some technical background and practicing engineers or physicists working in imaging industries should also find it a valuable reference in the medical imaging field. As a final note, it should be pointed out that there are other imaging methods that have been used in medicine [e.g., thermography, magnetic imaging, and microwave imaging (Hendee, 1991)]. They are not included in this book primarily due to their limited utility at present. Readers who are interested in these modalities may refer to several books listed in the following reference section.

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